IMPROVED SUSY QCD CORRECTIONS TO HIGGS BOSON DECAYS INTO QUARKS AND SQUARKS

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The $\mathcal{O}(\alpha_s)$ SUSY QCD corrections to the decays of the MSSM Higgs bosons into bottom quarks and squarks can be very large for large $\tan\beta$ in the on–shell renormalization scheme. We improve the calculation by a careful choice of the tree-level Higgs boson couplings in terms of running parameters of quarks and squarks.

1 Introduction

The MSSM has two Higgs doublets (H_1, H_2) which give five physical bosons (h^0, H^0, A^0, $H^\pm$). Their couplings to bottom quarks b and squarks $\tilde{b}$ are enhanced for large $\tan\beta$. In this case the decays to b are usually the main modes.[1] Decays to $\tilde{b}$ can be also dominant.[2] Studying these decays is therefore very important.

These decays receive large SUSY QCD corrections.[3,4] When the on–shell scheme is adopted for quarks and squarks, the corrections are often very large and make the perturbation calculation quite unreliable. The large gluon loop correction can be absorbed by using the QCD running quark mass in the coupling. However, the gluino loop correction can also be very large for large $\tan\beta$.

Here we improve[5] the one–loop SUSY QCD corrected widths of the Higgs boson decays into quarks and squarks. The essential point of the improvement is to define appropriate tree–level couplings of the Higgs bosons to b and $\tilde{b}$.

2 Gluino corrections to Higgs–quark couplings

The main part of the large gluino loop corrections to the Higgs decay widths into b originates from the $\bar{b}bH_2$ coupling which is generated by squark–gluino loops.

At tree–level, the $\bar{b}bH_2$ coupling is forbidden by SUSY. However, the interaction $h_b\Delta_b\bar{b}bH_2$ is generated by the loop correction due to the soft SUSY breaking. The squark-gluino loops give $\Delta_b \sim \alpha_s m_{\tilde{g}}\mu/m_{\tilde{b}}^2$. Δ_b can have further contributions from other loop corrections.[6,7]

The effective interactions between Higgs bosons and b, after integrating out the squarks, are properly described by

$$\begin{aligned}\mathcal{L}_{\rm int}^{\rm eff} = &-(h_b/\sqrt{2})\bar{v}[\cos\beta+\Delta_b\sin\beta]\,\bar{b}b\\ &-(h_b/\sqrt{2})[\cos\alpha+\Delta_b\sin\alpha]\,H^0\bar{b}b\\ &+(h_b/\sqrt{2})[\sin\alpha-\Delta_b\cos\alpha]\,h^0\bar{b}b\\ &+(ih_b/\sqrt{2})[\sin\beta-\Delta_b\cos\beta]\,A^0\bar{b}\gamma_5 b\\ &+h_b[\sin\beta-\Delta_b\cos\beta]\,H^-\bar{b}_R t_L + (\text{h.c.}).\end{aligned} \tag{1}$$

The first term of Eq. (1) gives the (non–SUSY) QCD running mass $m_b(Q)_{\rm SM}$. The difference from the SUSY QCD running mass $m_b(Q)_{\rm MSSM} = (h_b/\sqrt{2})\bar{v}\cos\beta$ is enhanced by $\tan\beta$. As a result, the gluino loop correction to m_b can become very large[6] for large $\tan\beta$.

In Eq. (1) the contributions of Δ_b to the Higgs–bottom couplings take forms different from those to m_b. When the tree–

level couplings are given in terms of $m_b(Q)_{\rm SM}$ or the on–shell mass M_b, the corrections by Δ_b can be enhanced very much[7,5,8] for $\tan\beta \gg 1$. This is the main source of the large gluino loop corrections to decay widths to b in the on–shell scheme. Note that Δ_b itself is smaller than one and therefore does not destroy the validity of the perturbation expansion.

We can improve the QCD perturbative expansion by changing the choice of the tree–level Higgs-bottom couplings. For example, when the tree–level $A^0\bar{b}b$ coupling is expressed in terms of $m_b(Q)_{\rm MSSM}$ at $Q = m_A$, the correction from Δ_b becomes very small. We therefore expect that $m_b(Q)_{\rm MSSM}$ is an appropriate parameter for the $A^0 \to \bar{b}b$ decay. This is also the case for the $H^+ \to t\bar{b}$ decay. The H^0 and h^0 decays need a special treatment. For very large m_A, the $H^0\bar{b}b$ and $h^0\bar{b}b$ couplings are properly parametrized by $m_b(Q)_{\rm MSSM}$ and $m_b(Q)_{\rm SM}$, respectively. In general, the appropriate tree–level couplings are given by their linear combinations.

3 Higgs–squark couplings

The large SUSY QCD corrections to the Higgs decays into squarks in the on–shell scheme[4] mainly come from the counterterms for the Higgs–squark couplings, which depend on $(m_q,\ \theta_{\tilde{q}},\ A_q)$. As in the decays to quarks, we can improve the perturbation calculation by using SUSY QCD running parameters $m_q(Q)_{\rm MSSM}$ and $A_q(Q)$ in the tree–level couplings. However, the mixing angles $\theta_{\tilde{q}}$ are kept on–shell in order to cancel the $\tilde{q}_1 - \tilde{q}_2$ mixing squark wave function corrections.

4 Numerical results

We calculated[5] the one–loop SUSY QCD corrected widths of the Higgs boson decays to b and $\tilde{b}$, with and without the improvement presented here. In obtaining $m_b(Q)_{\rm MSSM}$ from $m_b(Q)_{\rm SM}$, we express the sbottom parameters in the sbottom–gluino loops in terms of $m_b(Q)_{\rm MSSM}$ and perform an iteration procedure. The large higher-order gluino corrections to m_b are then resummed.[5,8]

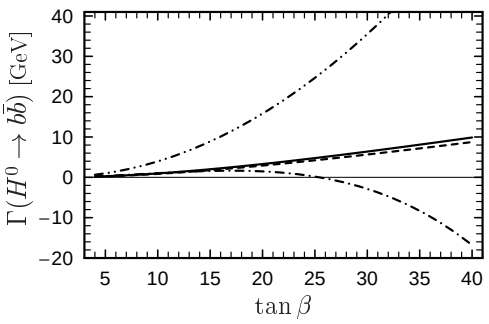

Figure 1. Decay width of $H^0 \to b\bar{b}$ as a function of $\tan\beta$. Dash–dot–dotted, dash–dotted, dashed, and full lines correspond to the on–shell tree–level, on–shell one–loop, improved tree–level, and improved one–loop results, respectively. The SUSY parameters are $(M_{\tilde{Q}}, M_{\tilde{U}}, M_{\tilde{D}}) = (300, 270, 330)$ GeV, $A_t = 150$ GeV, $A_b(Q = m_A) = -700$ GeV, $(m_{\tilde{g}}, \mu, m_A) = (350, 260, 800)$ GeV.

Here we show the tree–level and corrected widths of the decay $H^0 \to b\bar{b}$ in Fig. 1, and those of the decay $H^0 \to \tilde{b}_1\tilde{b}_1^*$ in Fig. 2. One can clearly see that the differences between tree–level and corrected widths decrease dramatically by our method, demonstrating the improvement of the perturbation expansion.

5 Summary

We have improved the SUSY QCD corrections to the Higgs decays into b and $\tilde{b}$. The essential point of the improvement is to define appropriate tree–level couplings of the Higgs bosons to b and $\tilde{b}$, in terms of the running parameters of quarks and squarks. We have also shown the numerical improvement of the SUSY QCD corrected decay widths.

We note that our method will also be useful in studying other processes with Higgs bosons.

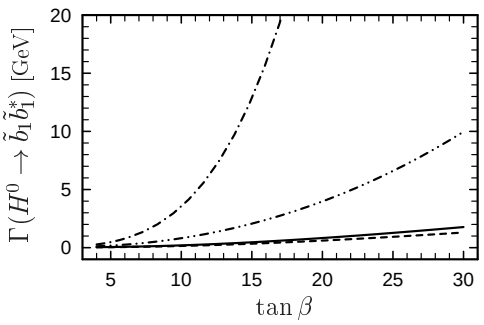

Figure 2. Decay width of $H^0 \to \tilde{b}_1 \tilde{b}_1^*$ as a function of $\tan\beta$. Notations and parameters are the same as in Fig. 1.

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